

JLAB PROTON POLARIZATION DATA IN ASPECT TO GLOBAL UNITARY AND ANALYTIC MODEL OF NUCLEON ELECTROMAGNETIC STRUCTURE¹

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Abstract

It is demonstrated that new JLAB proton polarization data, which are in a rather strong disagreement with the proton electric form factor data in the space-like region obtained by Rosenbluth technique, are consistent with all known form factor properties, including also the QCD asymptotics, but they require an existence of a zero (i.e. a diffraction minimum) around $t=15 \text{ GeV}^2$ of the proton electric form factor. The latter leads to a change of our knowledge about the charge distribution inside of the proton.

1 Introduction

The proton is charged particle compound of the (u , u , d) quarks and therefore it is non-point like. As a consequence one doesn't know an explicit form of the proton matrix element of the electromagnetic (EM) current

$$J_\mu^{EM} = 2/3 \bar{u} \gamma_\mu u - 1/3 \bar{d} \gamma_\mu d - 1/3 \bar{s} \gamma_\mu s \quad (1)$$

and therefore the latter is parametrized

$$\langle p | J_\mu^{EM} | p \rangle = \bar{u}(p') \left\{ \gamma_\mu F_{1p}(t) + i \frac{\sigma_{\mu\nu} q_\nu}{2m_p^2} F_{2p}(t) \right\} u(p) \quad (2)$$

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through Dirac $F_{1p}(t)$ and Pauli $F_{2p}(t)$ form factors (FF's), where $t = q^2 = (p' - p)^2 = -Q^2$ is a four momentum transferred by the virtual photon. From a practical point of view it is advantageous to introduce Sach's FF's

$$\begin{aligned} G_{Ep}(t) &= F_{1p}(t) + \frac{t}{4m_p^2} F_{2p}(t) \\ G_{Mp}(t) &= F_{1p}(t) + F_{2p}(t) \end{aligned} \quad (3)$$

to be normalized to the proton charge $G_{Ep}(0) = 1$ and the proton magnetic moment $G_{Mp}(0) = 1 + \mu_p$ ($\mu_p = 1.793[\mu]$ is the proton anomalous magnetic moment) and commonly they are called proton electric and proton magnetic FF's, respectively.

Prior to the year 2000 all data on $G_{Ep}(t)$ and $G_{Mp}(t)$ in the space-like ($t < 0$) region were obtained by measuring (mainly at SLAC) the differential cross-section of elastic electron scattering on proton

$$\begin{aligned} \frac{d\sigma^{lab}(e^- p \rightarrow e^- p)}{d\Omega} &= \frac{\alpha^2 \cos^2(\theta/2)}{4E^2 \sin^4(\theta/2)} \frac{1}{1 + (\frac{2E}{m_p}) \sin^2(\theta/2)} \cdot \\ &\cdot \left[\frac{G_{Ep}^2(t) - \frac{t}{4m_p^2} G_{Mp}^2(t)}{1 - \frac{t}{4m_p^2}} - 2 \frac{t}{4m_p^2} G_{Mp}^2(t) \tan^2(\theta/2) \right] \end{aligned} \quad (4)$$

and utilizing the Rosenbluth technique in order to separate $G_{Ep}(t)$ and $G_{Mp}(t)$.

In such a way obtained data up to almost $t = -35 \text{ GeV}^2$ have with increased $Q^2 = -t$ smooth fall and the ratio $(1 + \mu_p)G_{Ep}(Q^2)/G_{Mp}(Q^2)$ has constant behavior at least up to $Q^2 = 6 \text{ GeV}^2$, where the electric and magnetic proton FF's follow the dipole formula [1,2]

$$G_{Ep}(Q^2) = G_{Mp}(Q^2)/(1 + \mu_p) = D(Q^2) = 1/(1 + \frac{Q^2}{0.71})^2. \quad (5)$$

More recently [3,4] Jefferson Lab data on $(1 + \mu)G_{Ep}(Q^2)/G_{Mp}(Q^2)$, measuring simultaneously transverse P_t and longitudinal P_l components of the recoil proton's polarization in the electron scattering plane of the polarization transfer process $\vec{e}p \rightarrow e\vec{p}$, have been determined at the region $0.3 \text{ GeV}^2 \leq Q^2 \leq 5.6 \text{ GeV}^2$ by the relation

$$\frac{G_{Ep}}{G_{Mp}} = -\frac{P_t}{P_l} \frac{E + E'}{2m_p} \tan^2(\theta/2), \quad (6)$$

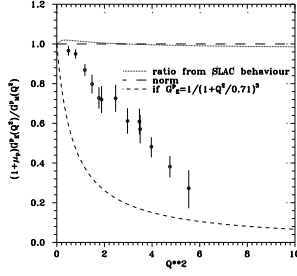


Figure 1: Remarkable fall of $G_{Ep}(Q^2)$ with increased Q^2 in comparison with $G_{Mp}(Q^2)$

which reveal a remarkable fall of $G_{Ep}(Q^2)$ (see Fig.1) with increased Q^2 in comparison with $G_{Mp}(Q^2)$ and so, this data are in a rather strong disagreement with the data obtained by Rosenbluth technique.

In this contribution we solve this puzzle by an investigation of a compatibility of new data with all known FF properties in the framework of our global unitary and analytic model of the nucleon EM structure [5].

2 Global unitary and analytic model of nucleon EM structure

It is till now the most sophisticated model [5] for four independent analytic functions

$$\begin{aligned}
 G_{Ep}(t) &= [F_1^s(t) + F_1^v(t)] + \frac{t}{4m_p^2} [F_2^s(t) + F_2^v(t)] \\
 G_{Mp}(t) &= [F_1^s + F_1^v(t)] + [F_2^s(t) + F_2^v(t)] \\
 G_{En}(t) &= [F_1^s(t) - F_1^v(t)] + \frac{t}{4m_n^2} [F_2^s(t) - F_2^v(t)] \\
 G_{Mn}(t) &= [F_1^s - F_1^v(t)] + [F_2^s(t) - F_2^v(t)],
 \end{aligned} \tag{7}$$

so-called electric and magnetic proton and neutron FF's, to be defined on four-sheeted Riemann surface in t -variable with complex poles corresponding to unstable vector meson resonances placed only on unphysical sheets. The model contains all known FF

properties like experimental fact of a creation of vector-meson resonances in electron-positron annihilation processes into hadrons, the assumed nucleon FF analytic properties, unitary condition, normalization

$$F_1^s(0) = F_1^v(0) = 1/2; \quad F_2^s(0) = 1/2(\mu_p + \mu_n); \quad F_2^v(0) = 1/2(\mu_p - \mu_n), \quad (8)$$

and the asymptotic behaviour as predicted by quark model of hadrons

$$F_1^{s,v}(t)|_{|t| \rightarrow \infty} \sim t^{-2}; \quad F_2^{s,v}(t)|_{|t| \rightarrow \infty} \sim t^{-3}. \quad (9)$$

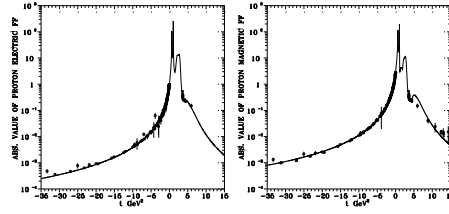


Figure 2: Description of $G_{Ep}(t)$ and $G_{Mp}(t)$ data by unitary and analytic model

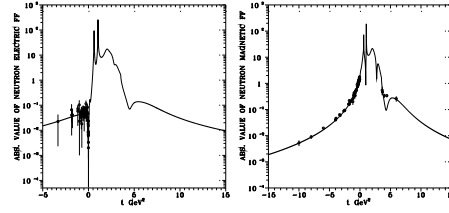


Figure 3: Description of $G_{En}(t)$ and $G_{Mn}(t)$ data by unitary and analytic model

In such a way it provides a very effective framework for a consistent superposition of complex conjugate vector-meson pole pair and continuum contributions with all other nucleon FF properties and describes well (see Figs. 2,3) first time all existing space-like (obtained by Rosenbluth technique) and time-like nucleon FF data simultaneously, despite of the fact that the obtained by Rosenbluth technique data on electric proton

FF $G_{Ep}(t)$ in $t < 0$ region are significantly less precise than the data on $G_{Mp}(t)$, since $G_{Mp}(t)$ is dominant in differential cross-section (4), from the experimental values of which both, $G_{Ep}(t)$ and $G_{Mp}(t)$, are extracted.

3 Consequences following from JLAB proton polarization data

From Fig.1 it is straightforward to see, that G_{Ep} fall is steeper than the fall of dipole formula, but less intense than tripole one.

Knowing the ratio G_{Ep}/G_{Mp} one can extract also data on the ratio F_{2p}/F_{1p} by the expression

$$\frac{F_{2p}(Q^2)}{F_{1p}(Q^2)} = \left(1 - \frac{G_{Ep}(Q^2)}{G_{Mp}(Q^2)}\right) / \left(\frac{G_{Ep}(Q^2)}{G_{Mp}(Q^2)} + \frac{Q^2}{4m_p^2}\right). \quad (10)$$

Then $Q^2 F_{2p}/F_{1p}$ indicates continuing increase (see Fig.4) with Q^2 . However, if we

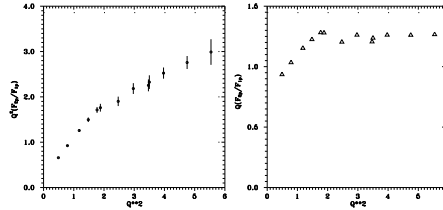


Figure 4: Data on F_{2p}/F_{1p} multiplied by Q^2 and Q respectively

multiply the data on ratio F_{2p}/F_{1p} only by Q , then they acquire constant behaviour with Q^2 . So, the new JLab proton polarization data indicate that the proton Pauli FF has (at least in the interval $1.8 GeV^2 \leq Q^2 \leq 5.6 GeV^2$) the behaviour

$$F_{2p}(Q^2) \sim Q^{-5} \quad (11)$$

which is in contradiction with the PQCD predictions [6],[7]

$$F_{2p}(Q^2)|_{|Q^2| \rightarrow \infty} \sim Q^{-6}. \quad (12)$$

If the latter is true, then from the definition of the proton electric FF (3) it follows that $|G_{Ep}(Q^2)|$ must to have a zero, i.e. diffraction minimum, at some higher Q^2 .

4 Solution of the puzzle

On the base of our analysis above we are now in the position:

- i) The data on $G_{Ep}(t)$ and $G_{Mp}(t)$ in $t < 0$ region, obtained by Rosenbluth technique from $d\sigma/d\Omega$, are compatible with all other existing nucleon FF data and all known FF properties, including also the QCD asymptotics.
- ii) The very precise JLab proton polarization data on $(1 + \mu_p)G_{Ep}(Q^2)/G_{Mp}(Q^2)$ contradict (at least in the region $1.8 \leq Q^2 \leq 5.6 GeV^2$) predictions of PQCD.

Now, what data on $G_{Ep}(t)$ in $t < 0$ region are true and what data are wrong?

In a solution of the latter problem we have proceeded as follows. Since the magnetic proton FF $G_{Mp}(Q^2)$ is (owing to the factor $\frac{t}{4m_p^2}$) dominant at the differential cross-section (4) of $e^-p \rightarrow e^-p$ (at $Q^2 = -t \approx 3 GeV^2$ the electric proton FF contributes only 5% to the cross-section value and for higher momenta it is even less), the obtained data on electric proton FF could be unreliable, even wrong. On the other hand, a simultaneous measurement of the transverse and longitudinal components of the recoil proton's polarization in the electron scattering plane of the polarization transfer process $\vec{e}^-p \rightarrow e^-\vec{p}$ is very effective and reliable method of a determination of the ratio G_{Ep}/G_{Mp} . As a result we believe in the obtained data presented in Fig.1 and their violation of QCD asymptotics given by (11) we consider to be a local effect.

This our conjecture we verify in the framework of the global unitary and analytic model of nucleon EM structure which contains the QCD asymptotics automatically. First, we exclude from the set of all existing proton and neutron EM FF data the space-like data on $G_{Ep}(t)$ obtained from $d\sigma/d\Omega$ by Rosenbluth technique. We substitute them for JLab proton polarization data on $(1 + \mu_p)G_{Ep}(t)/G_{Mp}(t)$. Then by means of the

10 -resonance unitary and analytic model of nucleon EM structure [5] we carry out a fitting procedure of all these data simultaneously which provides in such a way test of:

- i) consistency of the JLab proton polarization data with all other proton and neutron EM FF data
- ii) consistency of these data with the powerful tool of physics - the analyticity
- iii) their consistency with the asymptotic behaviour as predicted (up to logarithmic corrections) by QCD.

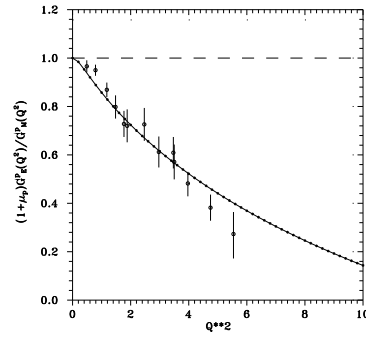


Figure 5: Description of the JLab proton polarization data by unitary and analytic model

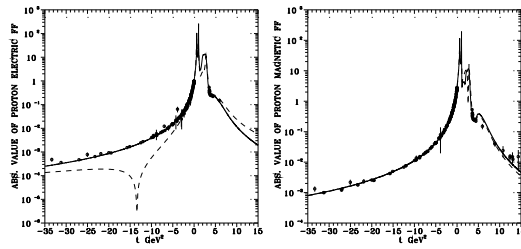


Figure 6: Results of the JLab proton $t < 0$ data analysis (dashed lines) for $G_{Ep}(t)$ and $G_{Mp}(t)$

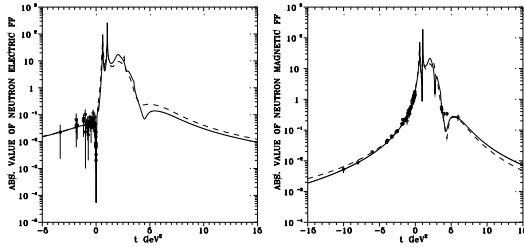


Figure 7: Results of the JLab proton $t < 0$ data analysis (dashed lines) for $G_{En}(t)$ and $G_{Mn}(t)$

We have obtained very surprising results. A perfect description of the JLab proton polarization data (see Fig.5) was achieved. The fitted parameters of the unitary and analytic model of nucleon EM structure are almost unchanged in comparison with those given in [5]. A description of the $G_{Ep}(t)$ time-like data, of all $G_{Mp}(t)$ data and space-like and time-like neutron EM FF data is (see dashed lines in Figs. 6,7) changed very little.

So, we come to the conclusion, that the JLab proton polarization data are consistent with all other existing nucleon EM FF data besides space-like $G_{Ep}(t)$ data obtained from $d\sigma(e^-p \rightarrow e^-p)/d\Omega$ by Rosenbluth technique. They are consistent with analyticity and they don't contradict the QCD asymptotics, however they strongly require an existence of the zero in $|G_{Ep}(t)|$ (i.e. a diffraction minimum well known in nuclear EM FF's) around $t = -15GeV^2$.

5 Conclusions and discussion

Recent JLab proton polarization data on $(1 + \mu_p)G_{Ep}(Q^2)/G_{Mp}(Q^2)$, obtained by a simultaneous measurement of the transverse and longitudinal components of the recoil proton's polarization in the electron scattering plane of the polarization transfer process $\vec{e}p \rightarrow e\vec{p}$ at the region $0.3GeV^2 \leq Q^2 \leq 5.6GeV^2$, revealed a remarkable fall of $G_{Ep}(Q^2)$ with increased Q^2 , which contradicts previous $G_{Ep}(t)$ data determined from $d\sigma(e^-p \rightarrow$

$e^-p)/d\Omega$ by Rosenbluth technique and so, also the QCD asymptotics.

Discarding all $G_{Ep}(t)$ data obtained by Rosenbluth technique in space-like region we have analyzed new JLab proton polarized space-like data together with all other nucleon EM FF data in the framework of the unitary and analytic model of the nucleon EM structure from Ref. [5].

On the basis of the obtained results we came to the conclusions, that the JLab proton polarization data are consistent with all nucleon EM FF data, besides space-like $G_{Ep}(t)$ data obtained by Rosenbluth technique, and also with QCD asymptotics, however, they require an existence of a zero (i.e. diffraction minimum) of $|G_{Ep}(t)|$ around $t = -15\text{GeV}^2$. So there is a challenge to experimental groups to confirm our conclusion by measuring $(1 + \mu_p)G_{Ep}(Q^2)/G_{Mp}(Q^2)$ at higher momenta.

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